Effect of high energy proton irradiation on J_c and B_{c2} of industrial Nb_3Sn wires

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The Nb_3Sn quadrupoles in the LHC Upgrade will be submitted to high energy radiation with various radiation sources, which will induce important changes on the superconducting properties of Nb_3Sn wires. In the present work, industrial Nb_3Sn wires with Ti and Ta additives (RRP process) and with Ta additives (PIT process) have been irradiated with protons of 65 MeV (UCL in Louvain) up to $1x10^{21}$ p/m^2 and of 24 GeV (CERN) up to $1.3x10^{21}$ p/m^2.

The proton beam was directed perpendicularly to the wire axis in order that the wires (1 mm diameter) were not affected by the Bragg peak. The critical current density J_c of the irradiated wires were determined by magnetization measurements up to 10T at temperatures up to 14K. The effect on the upper critical field B_{c2} was deduced from the Kramer extrapolation and by fitting. A steady increase of J_c vs. fluence was observed for all the wires, at all fluences. The variation of J_c was similar for both processing routes. This is in contrast to the effect of the alloying element, the variation for Ti alloyed wires being higher than that of the Ta alloyed wire. In spite of the very different proton energies, the enhancement of J_c was only little influenced between 65 MeV and 2 GeV: this may be explained by the small wire dimension with respect to the proton penetration depth at such high energy.

The results on the irradiated wires were analyzed based on the two-pinning mechanism model of T. Baumgartner [1]. Grain boundary pinning was found to be unchanged by irradiation, the increase of pinning force with fluence being essentially due to point pinning, originating from radiation induced defect clusters of nanosize dimensions (artificial pinning).

A comparison of the present data with neutron irradiation data with those of an ongoing neutron irradiation study undertaken in collaboration with the Atominstitut Vienna on the same Nb_3Sn wires shows that the radiation damage caused by protons is considerably higher than the damage after neutron irradiation: the same effect on J_c is obtained after proton fluences being more than one order of magnitude smaller [2]. In addition, proton irradiation is found to cause a higher B_{c2} enhancement when compared to neutron irradiation. Possible reasons for this difference are discussed.

References

[1] T. Baumgartner, PhD thesis, ATI Vienna, 2013.

[2] T. Spina, R. Flükiger, C. Scheuerlein, D. Richter, A. Ballarino and L. Bottura, presented at EUCAS 2012, submitted to Journal of Physics Conference Series (JPCS, IOP). Issue No. 27 of Superconductivity News Forum (SNF) http://www.ewh.ieee.org/tc/csc/global/